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The influence of reinforcement shape on wear behaviour of aluminium matrix composite materials

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Materials

ABSTRACT

Purpose: The purpose of this paper is to present the research results of modern metal matrix composite materials. The matrix material was EN AC - AlSi12 alloy while the reinforcement ceramic performs. In order to investigate the influence of reinforcing phase's shape on tribological properties the comparison was made between the composite material based on preforms obtained by Al_2O_3 Alcoa CL 2500 powder sintered with addition of pore forming agent in form of carbon fibres Sigrafil C 10 M250 UNS from Carbon Group company and composite materials based on much more expensive commercial fibrous preforms.
Design/methodology/approach: The composite was produced by the use of porous material pressure infiltration method. Obtained composite materials were examined with light and scanning electron microscopy. Hardness test was carried out with Rockwell method in A scale. Additionally, the wear resistance was measured by the use of device designed in the Institute of Engineering Materials and Biomaterials. The device realize dry friction wear mechanism of reciprocating movement conditions.
Findings: The obtained results show the possibility of manufacturing the new composite materials by the method of porous sintered framework pressure infiltration based on the ceramic particles, with desired microstructure and properties, being a cheaper alternative for materials with base of ceramic fibers.
Practical implications: Tested composite materials can be apply among the others in automotive and aircraft industries.
Originality/value: Worked out technology of composite materials manufacturing can be used in the production of near net shape and locally reinforced elements.
Keywords: Composites; Ceramic preforms; Infiltration; Tribological properties

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1. Introduction

The rapid progress in mobile and aircraft industry requires new materials with very good mechanical properties, rigidity, hardness, wear resistance and relatively low density. Ceramic fibres or particles reinforced aluminium matrix composites have attracted considerable attention in recent years because of their potential to exhibit enhanced mechanical properties in comparison to their individual components. However, the properties of light metal matrix composites depend not only on the individual properties of the matrix alloy and the reinforcing phase, but also to a large extent on the manufacturing technique, as the latter determines the microstructure of the material, the distribution of the reinforcing material in the matrix and the interfacial bonding between the reinforcing phase and the matrix [1].

Several development directions of manufacturing of the composite materials with aluminium alloys matrix are observed in the last dozen years. In general, among these trends one can indicate improvement of casting methods, powder metallurgy methods, and the porous ceramics infiltration method, mostly Al_2O_3 with metals alloys.

Pressure infiltration of the ceramic preforms is a method used more and more often in manufacturing of the composite materials with aluminium alloys matrix and has also become the topic of many research projects [2-11]. The composite materials used most often have only a single continuous phase (matrix); however, there is a growing interest in materials with two continuous phases. One of techniques used to obtain such structure is infiltration of the porous ceramics with liquid metals [2, 12, 13].

The main problem of manufacturing of the composite materials with the best tribological properties is the proper selection of reinforcement, their shape and portion, to improve the friction coefficient and not to degrease wear resistance simultaneously. The shape of reinforcement phase plays an important role in the friction processes and the wear of systems in which one element is made from composite material. Aluminium alloys are most ofen reinforced by short or long fibres and spherical or irregular polyhedrons particles. Least of all beneficial are the last one because their sharp edges intensify the wear of counter sample. The size of damages caused by the matrix' removing during friction of reinforcement particles depends on their shape. Taking into consideration this fact the least of all beneficial are sharp particles of Al_2O_3 staying even for a short time betweem acting elements because they can destroy the surface of matrix and counter sample. If the fibres is spalled the damages are much smaller, because it plays a role of rolling element (something like a needle bearing) and then even the smoothing of cavities by rolling fibres is observed. [14].

The goal of the work is to investigate the influence of reinforcement shape on tribological properties of the EN AC - AlSi12 alloy matrix composite material reinforced with the ceramic preforms based on Al_2O_3 particles or fibres manufactured by pressure infiltration method.

2. Experimental procedure

2.1. Microstructure

The material for investigation was produced by the method of pressure infiltration of porous ceramic preforms with liquid aluminium alloy. The composites matrix consisted of euthetic alloy EN AC - AlSi12 which chemical composition is presented in Table 1 and as the reinforcement the porous ceramic frameworks were used accordingly consisted of Al_2O_3 particles and fibres.

Table 1.
Chemical composition of EN AC-AlSi12 aluminium alloy

Mean mass concentration of elements, wt.%							
Si	Fe	Cu	Mn	Zn	Ti	Others	Al
12	≤0.55	≤0.05	≤0.35	≤0.15	≤0.2	≤0.15	The others

Ceramic preforms from Al_2O_3 particles were produced by Aloca CL 2500 powder sintering method with addition of pore forming agent in form of carbon fibres Sigrafil C 10 M250 UNS from SGL Carbon Group company. The chemical composition of the used ceramic powder with diameter D50 = 1.80 µm are shown in Table 2.

Table 2.
Chemical composition of Alcoa CL 2500 powder

Mean mass concentration of elements, wt.%						
Al_2O_3	Na_2O	Fe_2O_3	SiO_2	CaO	B_2O_3	The others
99.80	0.05	0.02	0.01	0.01	0.01	0.10

The manufacturing process of the ceramic preforms involved:

- preparation of Al_2O_3 powder and carbon fibres mixture
- pressing of prepared mixture
- sintering.

The Al_2O_3 powder was wet grinded in ball mill to destroy particles agglomerations. Into the suspension the 40% addition of mass carbon fibres were added and polyvinyl alcohol Moviol 18-8 soluted in water (binding agent). Mixture of powder prepared in such a way was dried by freezing and water sublimation in low pressure. Dry powder was sieve through a sieve No 250 µm, and then placed onto the flat surface and sprayed with destilated water to activate the polyvinyl alcohol. After 24h the powder was submitted to uniaxial pressing with laboratory Fontune TP 400 hydraulic press fitted with 45x65 mm. steel form. The pressure was 100MPa and pressing time was 15s. Mouldings were sintered in "Gero" pipe furnace in air atmosphere (20 l/min). The temperature during the sintering process was ensuring the carbon fibres degradation (heating by 10h in temp. 800 ºC) and Al_2O_3 powder sintering in temperature of 1500 ºC by 2h. The portion of the porous (ceramic phase) in preforms was established on the basis of geometric measurement of their weight with the known Al_2O_3 particles density. The porosity of the received semi-finished products was around 75% (25% ceramic phase content). For the comparison of properties of the composite materials on the base of the produced frameworks with materials reinforced by fibrous preforms for further studies the commercial semi-finished products were used with 25% portion of Al_2O_3 fibres.

Both types of preforms, were squeeze infiltrated with AlSi12 alloy. Before infiltration the preforms were heated up to the temperature of 800°C to prevent premature melt solidification. The EN AC -AlSi12 aluminium alloy was superheated to 800ºC. Scheme of form used in infiltration process is presented in Fig .1. During infiltration process the following steps took place sequentially:

- placing the heated preform into the die,
- pouring the melt into cavity,
- placing the upper punch,
- pressing in hydraulic platen press with a plunger speed 17mm/s and a maximum pressure of 100MPa.

After solidification the composite was ejected and cooled by compressed air flow.

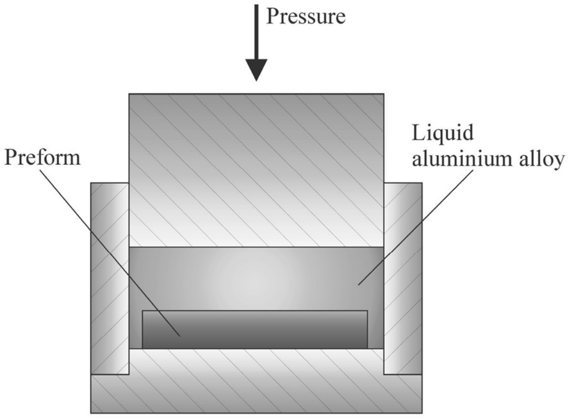


Fig. 1. Scheme of form used in infiltration process

2.2. Microstructure observations

Metallographic examinations of the both composite materials with aluminium alloy EN AC - AlSi12 matrix reinforced by porous preforms based on Al_2O_3 particles or fibres were made on the light microscope LEICA MEF4A. Specimens were not etched to observe the structure (ceramic phase distribution in the metal matrix) and the infiltration degree. There were also made observations of the wear track structure on the light microscope LEICA MEF4A and in the Zeiss Supra 25 scanning electron microscope.

2.3. Hardness and trybology tests

Hardness test was carried out on hardness measuring instruments Zwick/ZHR and was done with Rockwell method in A scale. The test was taken out according to the standard PN – EN ISO 14577-1:2003.

The wear resistance was measured by the use of device designed in the Institute of Engineering Materials and Biomaterials (Fig. 2). The device realize dry friction wear mechanism of reciprocating movement condition. The samples preparation for examinations consisted of grinding by the use ob abrasive paper with grit # 1200 to obtain flat and smooth surface. On samples prepared in this way there were made investigations with the steel ball 8,7 mm diameter as counter-sample. Investigations were made with different number of cycles 1000, 2000, 3000, 4000, 5000, respectively 24, 48, 72, 96 and 120 m, and under different load 2.5, 5, 7.5, 10 N. Samples after examinations were rinsed in ultrasonic washer to clean its surface, and then the degree of wear was established on the base of geometrical measurements of wear track and calculation of its volume. The volume loss as the indicator of absolute wear is used when the mass lost is too small and difficult to estimate.

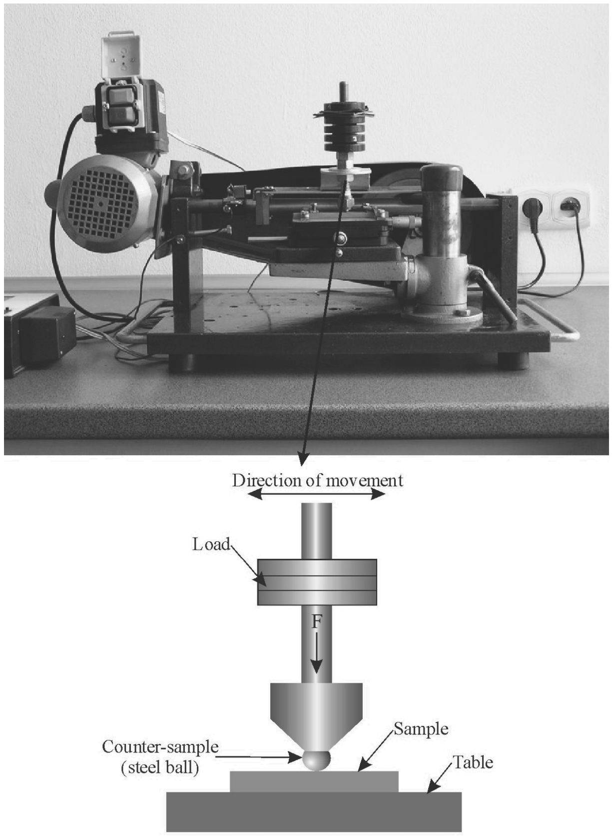


Fig. 2. The device used for wear resistance measurements

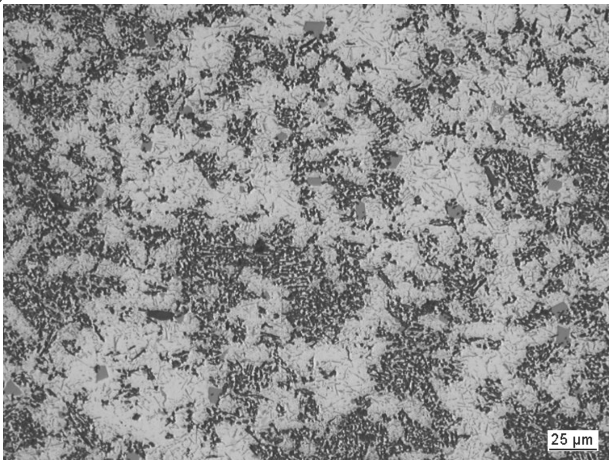
3. Experimental results and their discussion

The metallographic observations of the obtained composite materials based on preforms consisted of Al_2O_3 particles (Fig. 3a) as well as fibrous preforms (Fig. 3b) allow to notice the evenly distribution of reinforcing phase in the matrix. It was also found that infiltration process takes place at full level what have been proved by the lack of pores not filled with metal. Moreover, on the base of the structure of both materials it can be forecast that the composite material reinforced by ceramic particles, will have higher crack resistance along the grain boundaries metal-ceramic, because every particle is a barrier for spreading crack however along the fibre this process will occur on the comparatively long distance (fibre's length) without any obstacles.

Basing on hardness tests of the composite material hardness it was found to be almost 2.5 times higher compared to the EN AC - AlSi12 matrix material. The average matrix hardness is 19.19 HRA; whereas hardness values of the composite material manufactured by infiltration of the manufactured porous preforms is 47.30 HRA and 47.27 HRA in the case of material reinforced by commercial fibrous preform.

As a result of tribological measurements there were estimated the wear resistance in the condition of dry friction of composite materials reinforced by manufactured preforms, commercial fibrous preforms and their matrix (aluminium casting alloy EN AC - AlSi12). There were made investigation of the reinforcement shape, load and number of cycles (friction distance) influence on the wear of investigated materials.

a)



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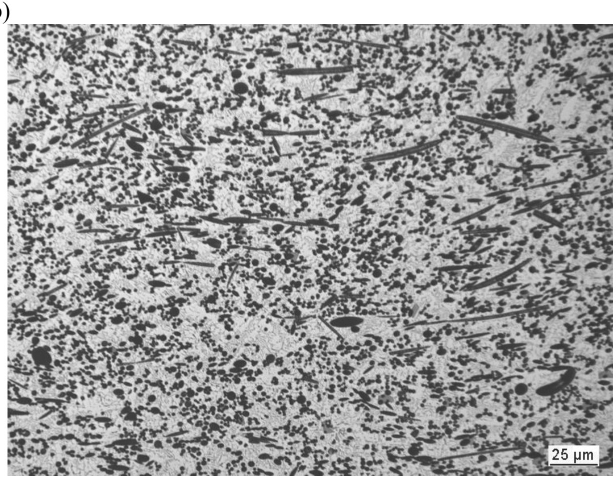
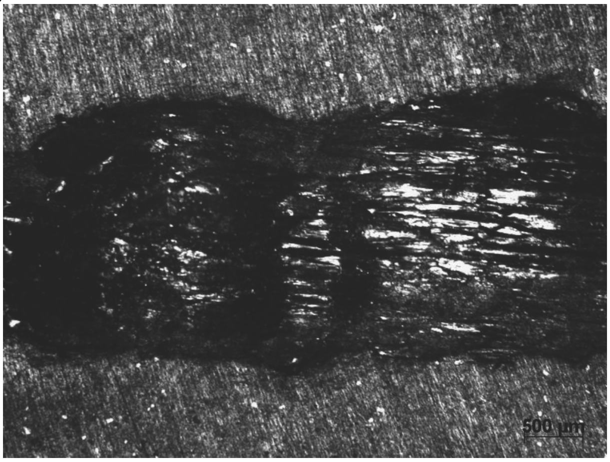


Fig. 3. Structure of the composite material with the aluminium alloy matrix reinforced with the: a) manufactured preform, b) commercial fibrous preform

a)



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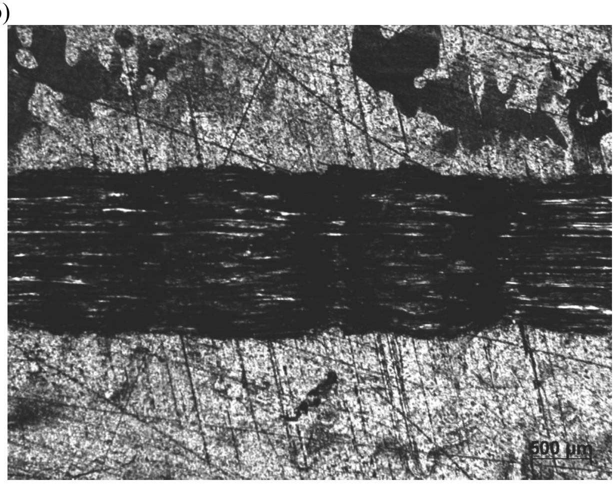


c)

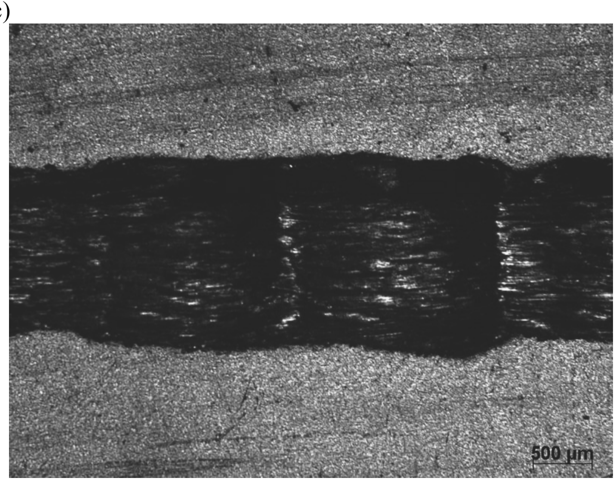


Fig. 4. Structure of wear track: a) aluminium casting alloy EN AC - AlSi12, b) composite material reinforced by manufactured preform and c) composite material reinforced by commercial fibrous preform

The character of wear track after 5000 cycles under load of 10 N on the light microscope are presented in Fig. 4 and the structure of tribological wear observed in scanning electron microscope in Fig 5. Non-uniform width of wear track testifies the scuffing effect. During scuffing process on the counter-sample the wear products are adhered and torn of in another place, that is the reason of local surface irregularity, in the vicinity which the wear is lower. In order to reduce the influence of the mentioned process on the results, the width of wear track were measured in the widest place.

The size of damage caused by the removal of reinforment from matrix during friction process in lagre measure depends on its shape. Least of all benefis are hard and sharp Al_2O_3 particles, which staying even for short time between acting element destroy their surface. (Fig. 5b). Surface's damages are much smaller when during the friction process the spalling of ceramic fibres took place (Fig. 5c), because it plays a role od rolling element. Sometimes even smoothing of cavities by rolling fibres took place. Because of that the structure of wear track in the case of matrix' sample and composite material reinforced by fibreous perform (Fig. 5a and 5c) is smooth and in the case of performs made from ceramic particles (Fig. 5b) numerous scratch are visilbe.

The results of friction measurements show that worked out composite materials characterized by much lower friction wear – 0.77 mm^3 for composite material reinforced by manufactured preform and 0.73 mm^3 for composite material reinforced by commercial fibrous preform, in comparison with aluminium casting alloy EN AC - AlSi12 which were used as the matrix (2.62 mm^3). Data concern results obtained after 5000 cycles under the load of 10 N. The wear of both composite materials and their matrix increases linearly with the growth of load and friction distance Fig. 6.

4. Conclusions

The metallographic observation of the obtained composite materials shown that the presented technology of manufactured the composite material with the EN AC - AlSi12 alloy matrix reinforced with the Al_2O_3 preforms, obtained by the pressure infiltration, ensures the required structure. The reinforcing phase in matrix is uniformly distributed. More over it can be concluded that if the process of infiltration was complete, all pores are fulfilled with liquid matrix material.

Tribological investigations reveal considerable increase of wear resistance of both worked out composite material in comparison with their matrix. It was proved that the wear level of composite material is directly proportional to the load of counter sample and friction distance (number o cycles). The higher wear resistance of these materials is connected with hardness higher value. The structure of materials depends mainly on the shape of reinforcement.. In the case of matrix sample and composite materials reinforced bys fibreous perform the surface of wear track is smooth while in the case of composite materials reinforced by manufactured perform there are visible numerous scratches caused by Al_2O_3 particles pulled out from the matrix, which stay for a short time between working elements. Spalling fibres do not cause this kind of damages because during the friction process the are rolling on the sample surface.

a)

b)

c)

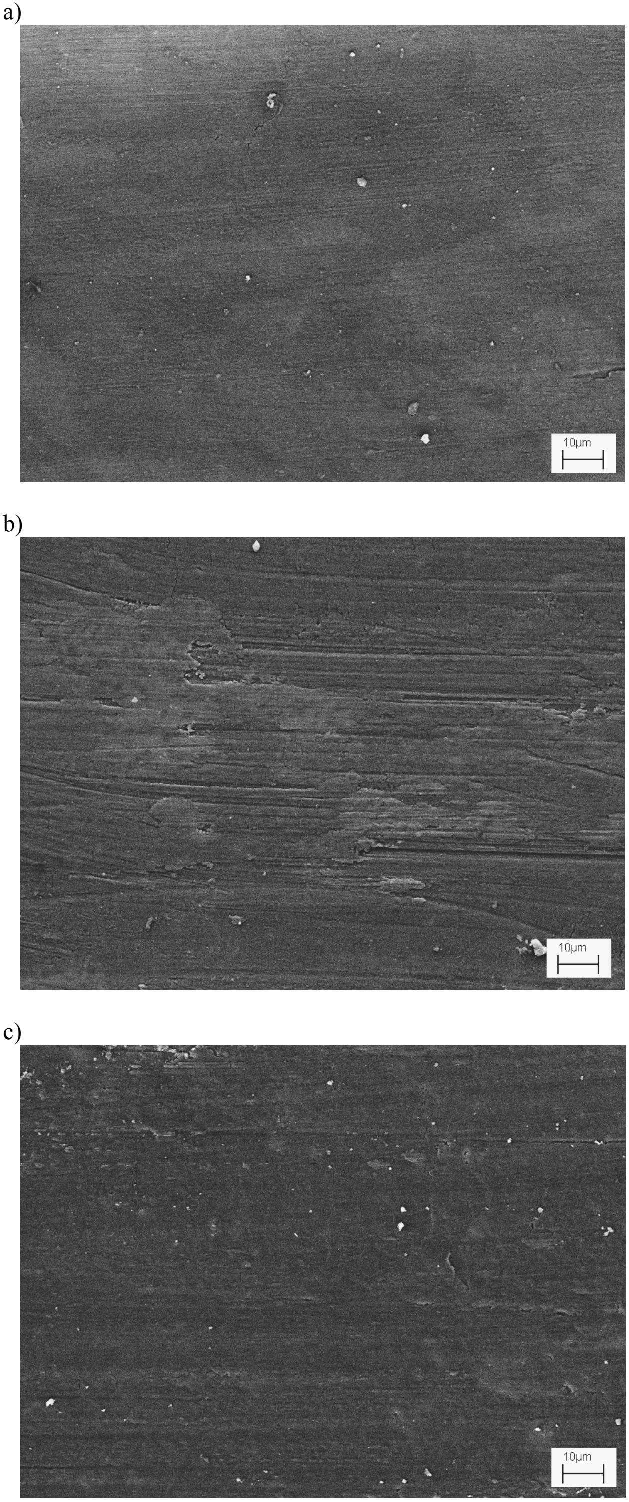
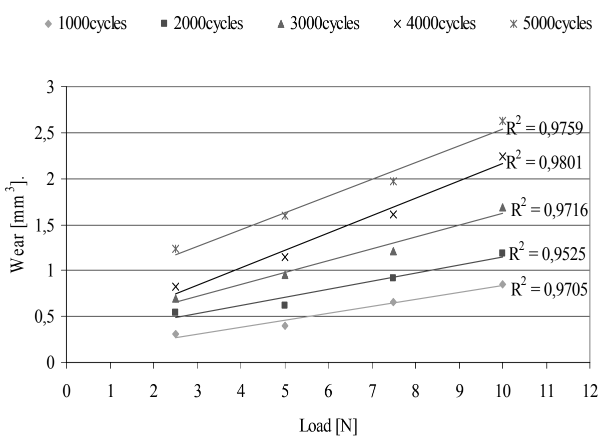


Fig. 5. Structure of wear track: a) aluminium casting alloy EN AC - AlSi12, b) composite material reinforced by manufactured preform and c) composite material reinforced by commercial fibrous perform

a)



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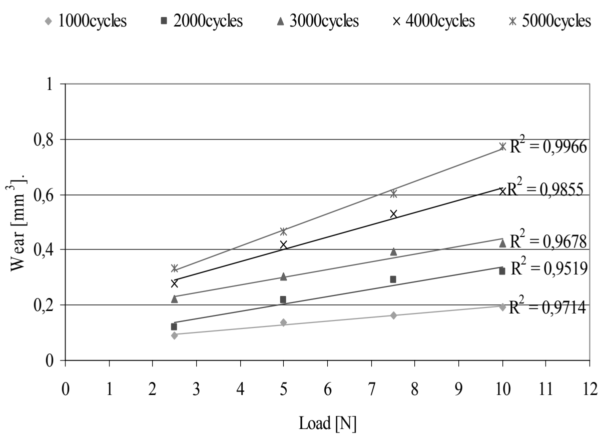

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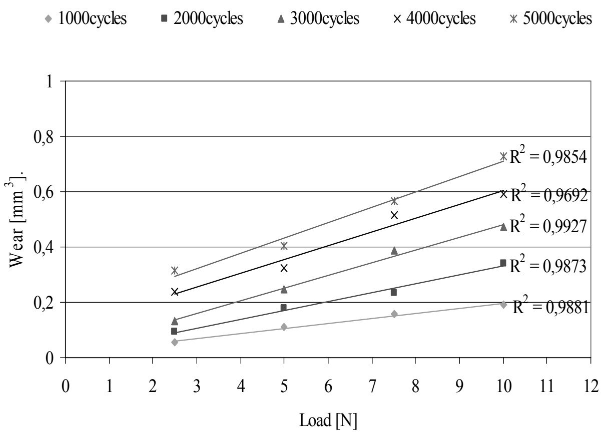

Fig. 6. The influence of load and friction distance on the wear of: a) aluminium casting alloy EN AC - AlSi12, b) composite material reinforced by manufactured preform and c) composite material reinforced by commercial fibrous preform

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Additional information

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